# RESEARCH MEMORANDUM

## INVESTIGATION OF INLET CONTROL PARAMETERS FOR AN EXTERNAL-INTERNAL-COMPRESSION INLET FROM MACH 2.1 TO 3.0

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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## SUMMARY

Investigation of the control parameters of an external-internal-compression inlet indicates that the cowl-lip shock provides a signal to position the spike and to start the inlet over a Mach number range from 2.1 to 3.0. Use of a single fixed probe position to control the spike over the range of conditions resulted in a 3.7-count loss in total-pressure recovery at Mach 3.0 and $0^{\circ}$ angle of attack. Three separate shock-sensing-probe positions were required to set the spike for peak recovery from Mach 2.1 to 3.0 and angles of attack from $0^{\circ}$ to $6^{\circ}$.

When the inlet was unstarted, an erroneous signal was obtained from the normal-shock control through most of the starting cycle that prevented the inlet from starting. Therefore, it was necessary to override the normal-shock control signal and not allow the control to position the terminal shock until the spike was positioned.

## INTRODUCTION

In general, variable features of supersonic inlets serve two purposes: To obtain optimum supersonic compression by positioning the shock-generating surfaces and to vary the airflow spillage for engine-inlet matching. In controlling variable inlets, both of these functions must be considered.

In some applications these functions have been combined by having the variable shock-generating surface regulate the flow spillage. Controls for this type of inlet are discussed in references 1 and 2. The control of inlets in which the two functions are separate is discussed in references 3 and 4. The external-internal-compression inlet described in reference 5 incorporated internal contraction that was varied by means of a translating spike. Centerbody positioning of this inlet is further

*Title, unclassified.

complicated because overcontraction of the inlet causes shock expulsion and undercontraction causes large recovery losses.

The inlet described in reference 5 was designed so that the oblique shock emanating from the cowl intersected the centerbody shoulder at optimum internal contraction at Mach numbers from 3.0 to 2.0. Below Mach 2.0, the spike was designed to remain fixed relative to the maximum throat area.

An investigation was made to determine the feasibility of using the first cowl oblique shock as a means of positioning the spike as well as using a static pressure in the diffuser duct to regulate airflow spillage. Data were taken in the NACA Lewis 10- by 10-foot supersonic wind tunnel at Mach numbers from 2.1 to 3.0 and angles of attack from 0° to 6°.

## SYMBOLS

$M$ Mach number

$m$ mass flow

$P$ total pressure, lb/sq ft

$p$ static pressure, lb/sq ft

$\alpha$ angle of attack, deg

$\theta_l$ angle between axis of spike and line joining cone apex and cowl lip, deg

Subscripts:

$r$ reference signal

$s$ sensing signal

$0$ free stream

$3$ compressor-face station

## APPARATUS AND PROCEDURE

A schematic diagram of the inlet described in reference 5 is shown in figure 1. This inlet was designed so that the cowl-lip oblique shock intersects the centerbody shoulder at optimum contraction from Mach 3.0 to 2.0. The spike position was controlled by sensing the location of the first oblique shock emanating from the cowl by means of a translating Pitot probe extending from the centerbody at the bottom of the inlet. A Pitot probe near the cowl provided the reference pressure. A detailed diagram of the sensing and reference probes is shown in figure 2.

The sensing and reference probes were connected to a differential pressure transducer (fig. 1). The voltage output, which is proportional to the difference between the reference and sensing signal, was fed into an electronic switching unit, where the upper and lower voltages of a dead band were set. The switching unit controlled the centerbody screw-jack actuator, which extended or retracted the spike when the transducer signal was outside the dead band. Air spillage through a bypass was simulated in this investigation by varying the position of the screwjack-actuated exit plug. The control loop for control of the exit plug was separate from the spike control and made use of terminal-shock location. A choice of four static-pressure orifices, located in the diffuser duct as shown in figure 3, was available to sense the location of the terminal shock. These static orifices were connected to pressure transducers and were referenced to a constant pressure. The transducer output voltage was fed into the electronic switching unit as in the spike-control loop.

Transient recordings of spike, plug, and probe position, together with spike and normal-shock signal, were made at Mach 3.0 to 2.1 and angles of attack from $0^{\circ}$ to $6^{\circ}$.

## RESULTS AND DISCUSSION

### Oblique-Shock Control

The location of the oblique shock for optimum spike position over the range of conditions tested, as measured with a translating probe protruding from the centerbody on the bottom of the inlet, is shown in figure 4. At Mach 3.0, the angle between the oblique shock and the inside surface of the cowl increased with increased angle of attack (fig. 4(a)). At $0^{\circ}$ angle of attack and $\theta_l = 29.85^{\circ}$, the shock emanating from the spike tip impinged on the inside surface of the cowl at optimum spike retraction.

Comparison of a predicted and a measured shock location (fig. 4(b)) shows good agreement at Mach 2.5 and 3.0 at zero angle of attack. The predicted shock pattern was obtained by assuming linear variations of flow properties with conical flow-field angle. The flow behind the first cowl oblique shock was assumed to have the direction of the cowl.

The control set point at Mach numbers of 3.0, 2.8, 2.5, and 2.2 is compared with the maximum spike retracted position in figure 5. When the spike was retracted beyond the control set point, the sensing signal was higher than the reference signal because of variations in the shock strength caused by the conical flow field in front. This indicated to the control that the spike must be extended. When the spike was extended ahead of the control set point, the sensing probe passed ahead of the oblique shock, and the bow shock in front of the shock sensor formed at a higher Mach number. This caused the sensing signal to be lower than the reference signal, which indicated the inlet was undercontracted and the spike must be retracted. In the unstarted condition, the sensing pressure was lower than the reference pressure because of the variations in bow-shock strength due to the conical flow field. This indicated to the control that the spike must be extended. The control signal for Mach 3.0 when the inlet was unstarted is indicated in figure 5. Because the oblique-shock-sensing signal passed through zero, there was automatic altitude compensation. Differences in the maximum and minimum limits of the oblique-shock-sensing signal were obtained for probe locations other than the one shown in figure 5. This was caused by variations in shock strength due to the conical flow field in front of the probe.

There was little or no relative movement between the first cowl oblique shock and the centerbody with movement of the centerbody when the oblique shock from the spike impinged on the inside surface of the cowl at Mach 3.0, $\alpha = 0^{\circ}$, and $\theta_l = 29.85^{\circ}$. At the condition when shock impingement occurred, no interference with the control resulted.

The steady-state operation of the spike control is shown in figure 6, where the control set points are superimposed on the peak inlet performance curves. By using an optimum probe position for each control set point, the spike was positioned at a condition corresponding to peak recovery. The mass-flow plug, in this case, was manually set. This illustrates the ability of the control to set peak recovery. Because the oblique shock did not always fall on the centerbody shoulder at the peak-recovery position, a different probe position was necessary for each set point (shown in fig. 6).

Inlet performance obtainable with the spike control using three fixed probe positions, optimized for Mach number and angle of attack, is shown in figure 7. A probe position that would set peak performance at Mach 3.0 and zero angle of attack (circle symbol) would unstart the inlet at all other conditions by retracting the spike too far. A probe position to set peak inlet performance over a range of Mach numbers from 2.8 to 2.5 and $0^{\circ}$ angle of attack (square symbol) would unstart the inlet at $3^{\circ}$ and $6^{\circ}$ angle of attack and would result in a 2.5-count loss in total-pressure recovery at Mach 3.0 and $0^{\circ}$ angle of attack. A probe position that would set near peak recovery at $3^{\circ}$ and $6^{\circ}$ angle of attack (diamond symbol) can operate over the entire Mach number and angle-of-attack range, but will incur a recovery loss of 3.7 counts at the design condition

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(Mach 3.0 and 0° angle of attack). To position the spike for peak pressure recovery over the range of Mach numbers and angle of attack mentioned would require three shock-sensing probe positions. Below Mach 2.0, the optimum location of the spike remains fixed in a position that maintains the maximum throat area.

## Normal-Shock Control

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The normal-shock pressure signal that was obtained from a wall static orifice for Mach 3.0 and zero angle of attack is shown in figure 8, along with the control set point. Because the control pressure in the unstarted condition was lower than for peak recovery, the normal-shock control received an erroneous signal to decrease instead of increase the weight flow. As a result, the normal-shock control would not allow the inlet to start. This might be remedied by proper selection of a reference pressure or by means of an override signal that would cause bypass to open when the inlet is unstarted. Even when the inlet was started, the pressure signal never reached the value of the dead band except when the spike was near the optimum position. Therefore, the spike must be in position before the plug or bypass can be controlled.

## Oblique- and Normal-Shock Control Operation

A trace taken with both controls setting peak recovery is shown in figure 9. The inlet was initially unstarted by manually closing the plug too far. In figure 9(a) the spike control was turned on and was extending the spike. The signal to operate the plug was in the wrong direction and would have closed the plug; consequently, the plug was manually opened. After the inlet was started, as shown by the section of trace (fig. 9(b)), and the spike was near its set point, the normal-shock control was turned on. From this point on, the control action was automatic. The spike position was reset first (fig. 9(d)), followed by the plug (fig. 9(e)).

## SUMMARY OF RESULTS

In an investigation of the use of the cowl-lip oblique-shock and normal-shock sensing for control of an external-internal-compression inlet in the Lewis 10- by 10-foot supersonic wind tunnel, the following results were obtained:

1. The cowl-lip oblique shock as sensed by a total-head probe provided a signal to position the spike and to start the inlet over a Mach number range from 2.1 to 3.0.

2. Three separate shock-sensing-probe positions were required to control the spike for optimum contraction over a Mach number range from 2.5 to 3.0 and at angles of attack from $0^{\circ}$ to $6^{\circ}$. Use of a fixed probe position that would control the spike so that it remained started over the entire range resulted in a 3.7-count loss in total-pressure recovery at Mach 3.0 and $0^{\circ}$ angle of attack.

3. An erroneous signal was obtained from the normal-shock sensor, which would prevent the inlet from starting. Even when the inlet was started, the normal-shock signal never reached the dead band, except when the spike was near the optimum position. Therefore, it was necessary to override the control signal when the inlet was unstarted and to arrange the control to reset the spike first during the return to the control set point.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, July 14, 1958

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2. Wilcox, Fred A.: Investigation of a Continuous Normal-Shock Positioning Control on the Bypass of a Supersonic Inlet in Combination with the J34 Turbojet Engine. NACA RM E55J10, 1956.

3. Lessler, L. Abbott, and Nettles, J. Cary: Investigation to Mach Number 2.0 of Shock-Positioning Control Systems for a Variable-Geometry Inlet in Combination with a J34 Turbojet Engine. NACA RM E54I27, 1954.

4. Beheim, Milton A., and Yeager, Richard A.: Investigation of Control Signals for Variable Ramps of Twin-Duct Side Inlets. NACA RM E57G22, 1958.

5. Obery, Leonard J., and Stitt, Leonard E.: Performance of External-Internal Compression Inlet with Abrupt Internal Turning at Mach Numbers 3.0 to 2.0. NACA RM E57H07a, 1957.

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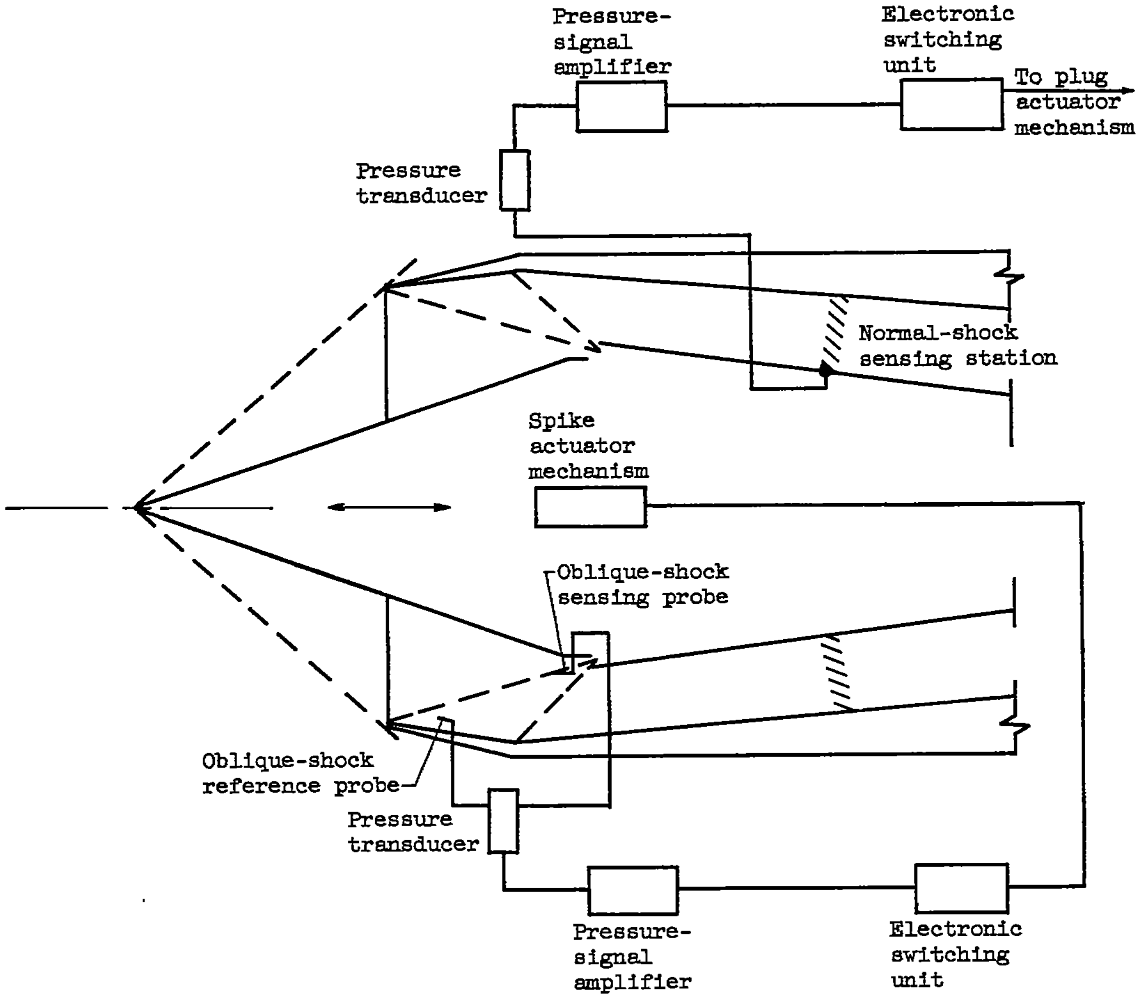


Figure 1. - Schematic diagram of oblique-shock and normal-shock control system.

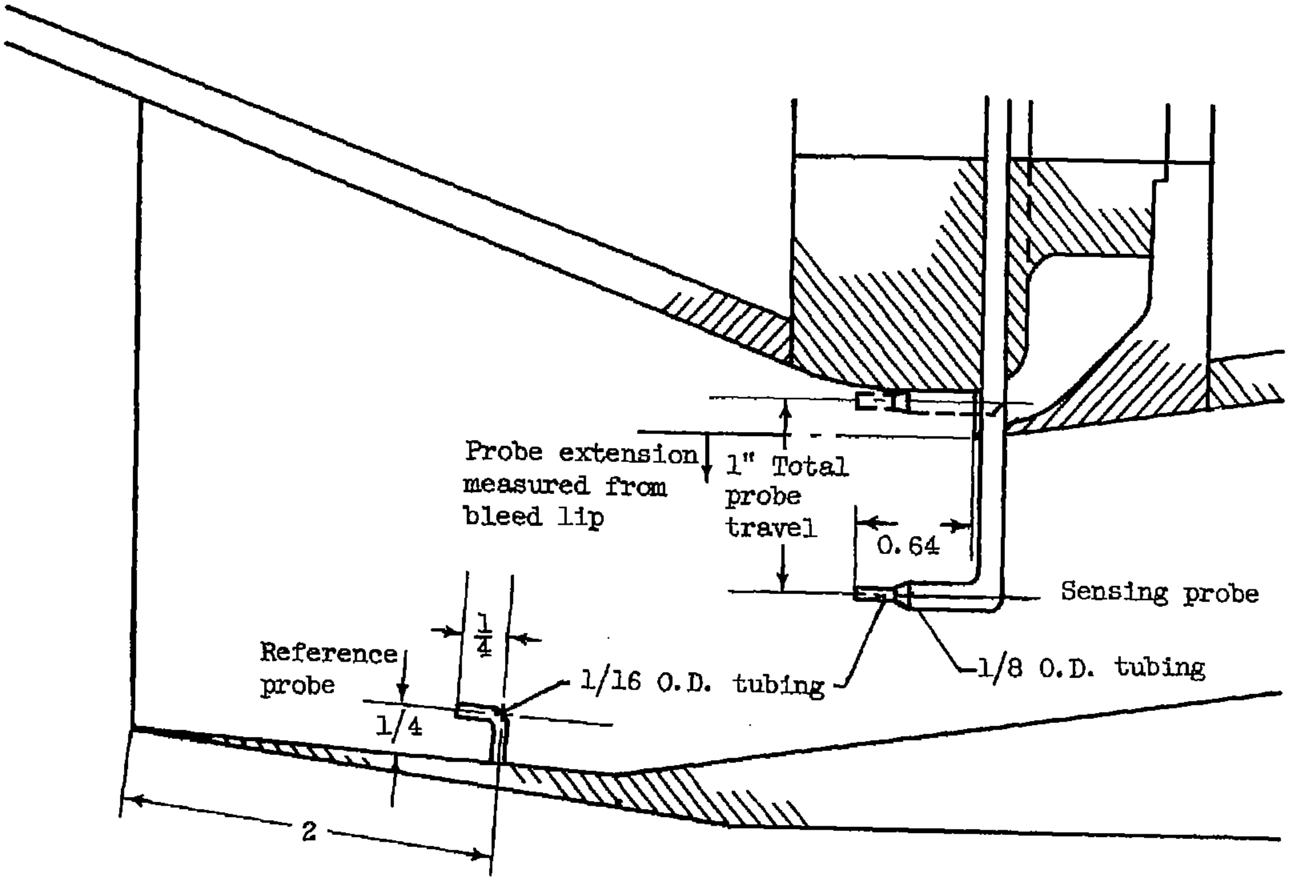


Figure 2. - Detail of sensing and reference probe for spike control (dimensions in inches).

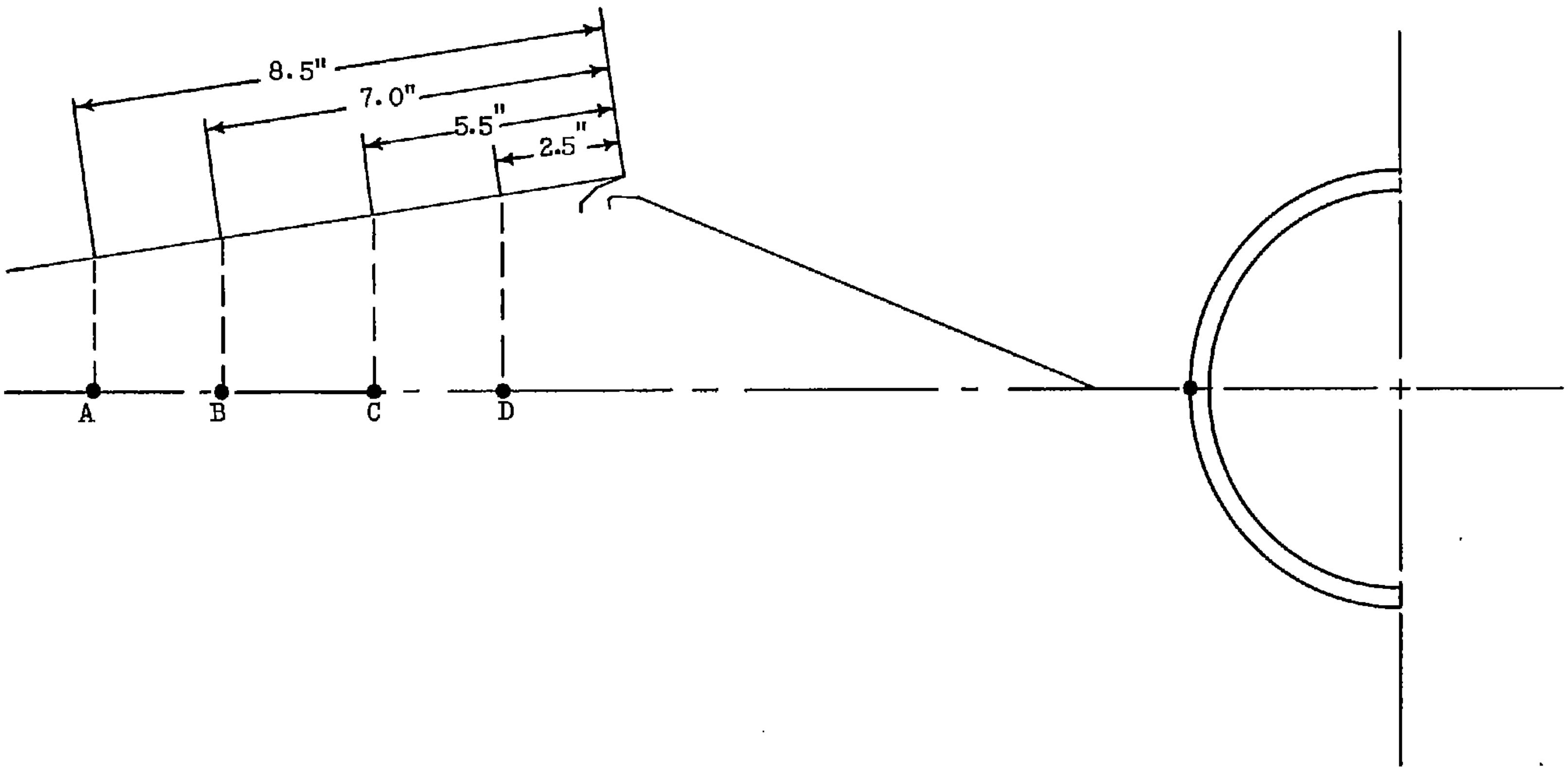


Figure 3. - Location of normal-shock-sensing stations.

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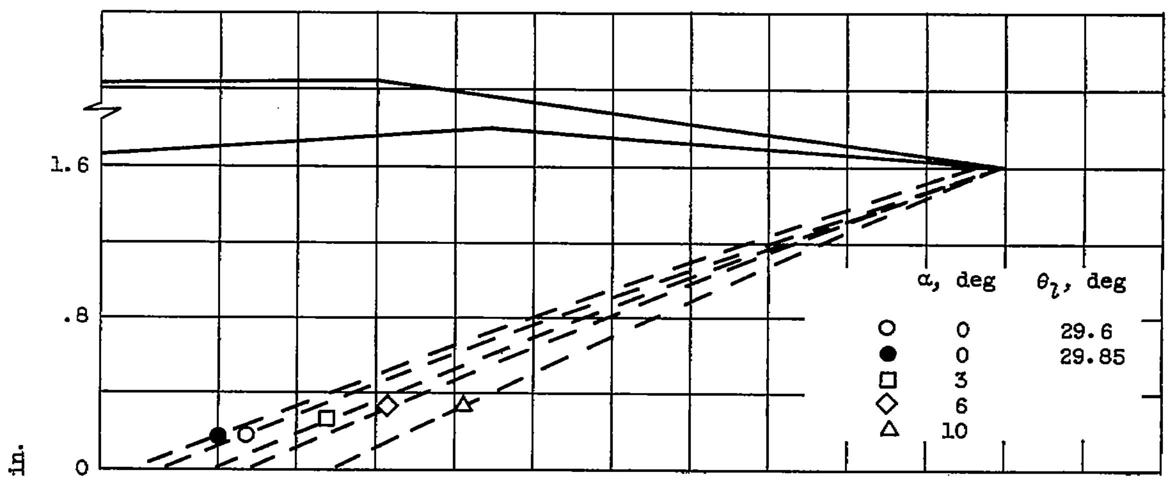
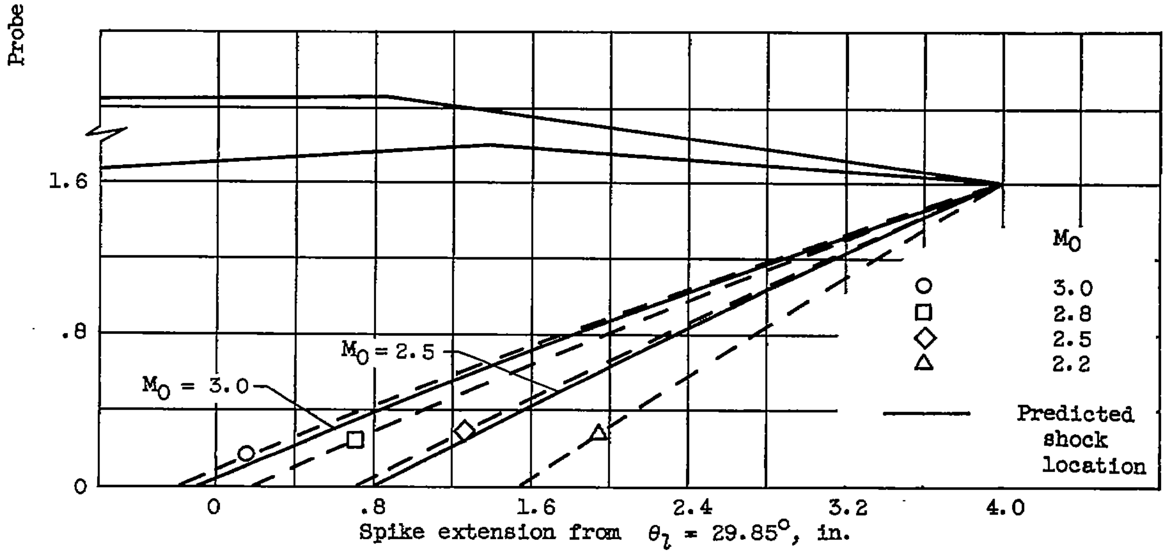



(a) Effect of angle of attack on oblique-shock location at Mach 3.0.




(b) Effect of Mach number on oblique-shock location at zero angle of attack.

Figure 4. - Location of cowl-lip oblique shock at optimum spike position.

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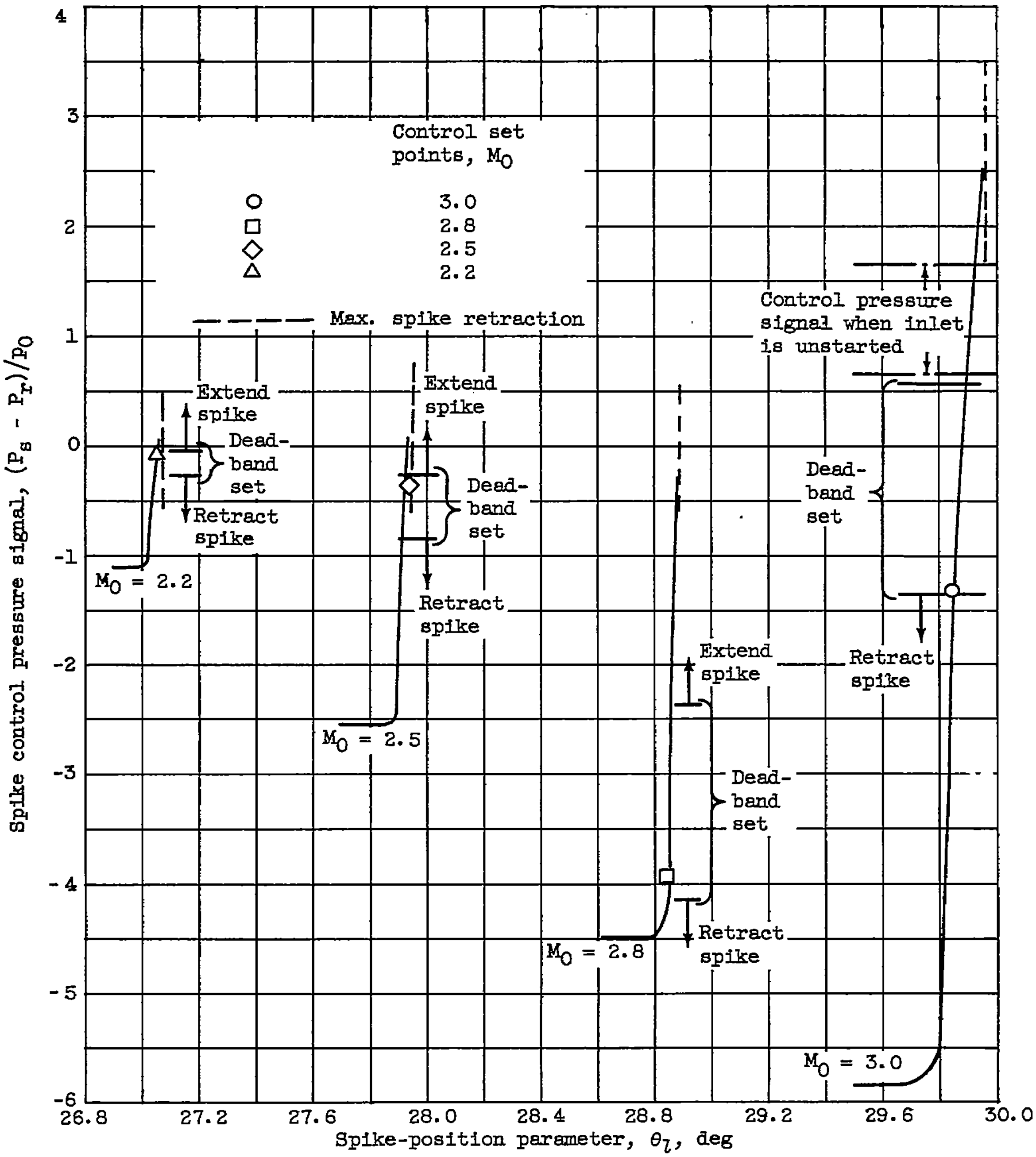


Figure 5. - Spike control pressure signal at zero angle of attack.

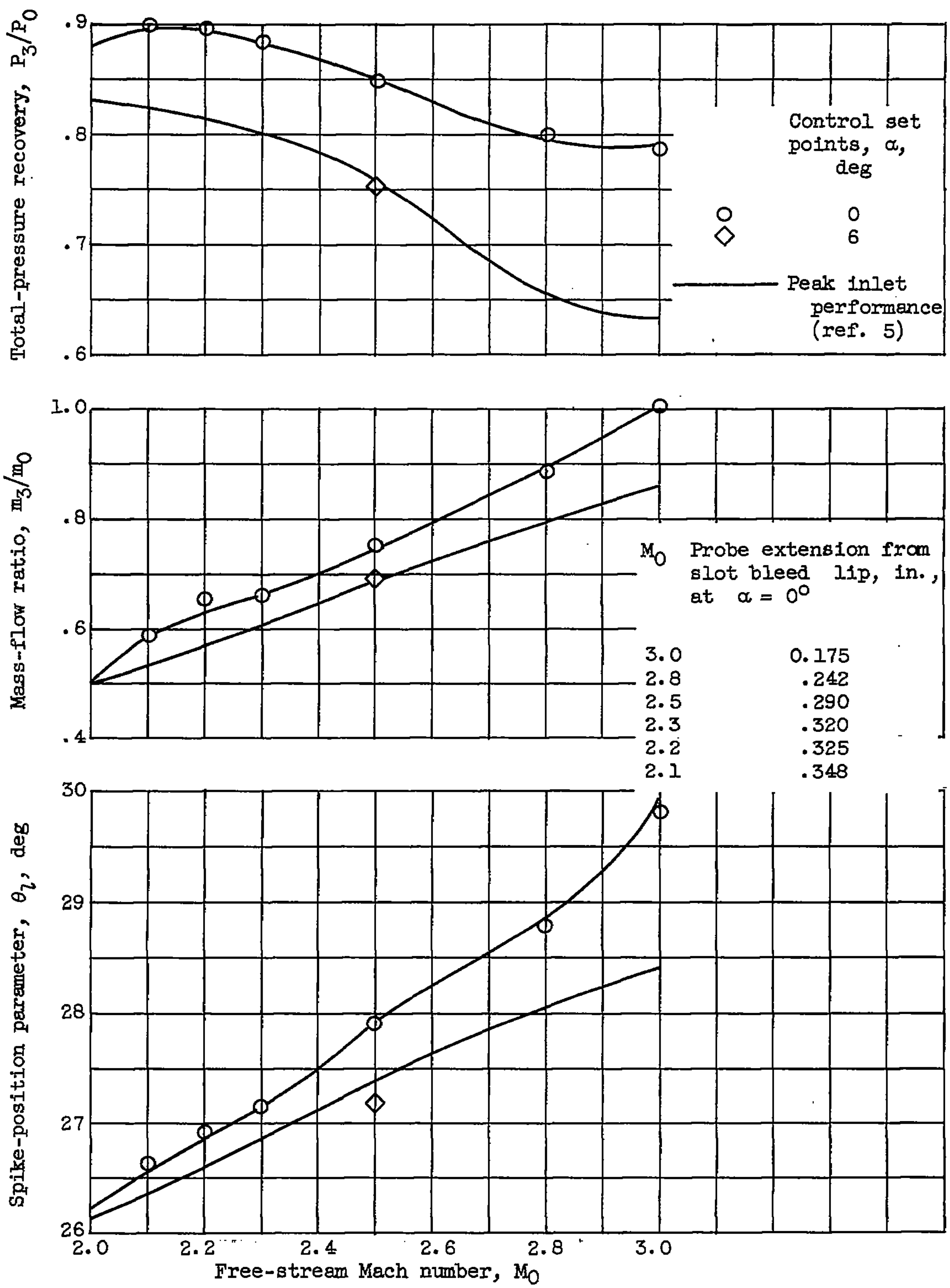


Figure 6. - Inlet performance set by control.

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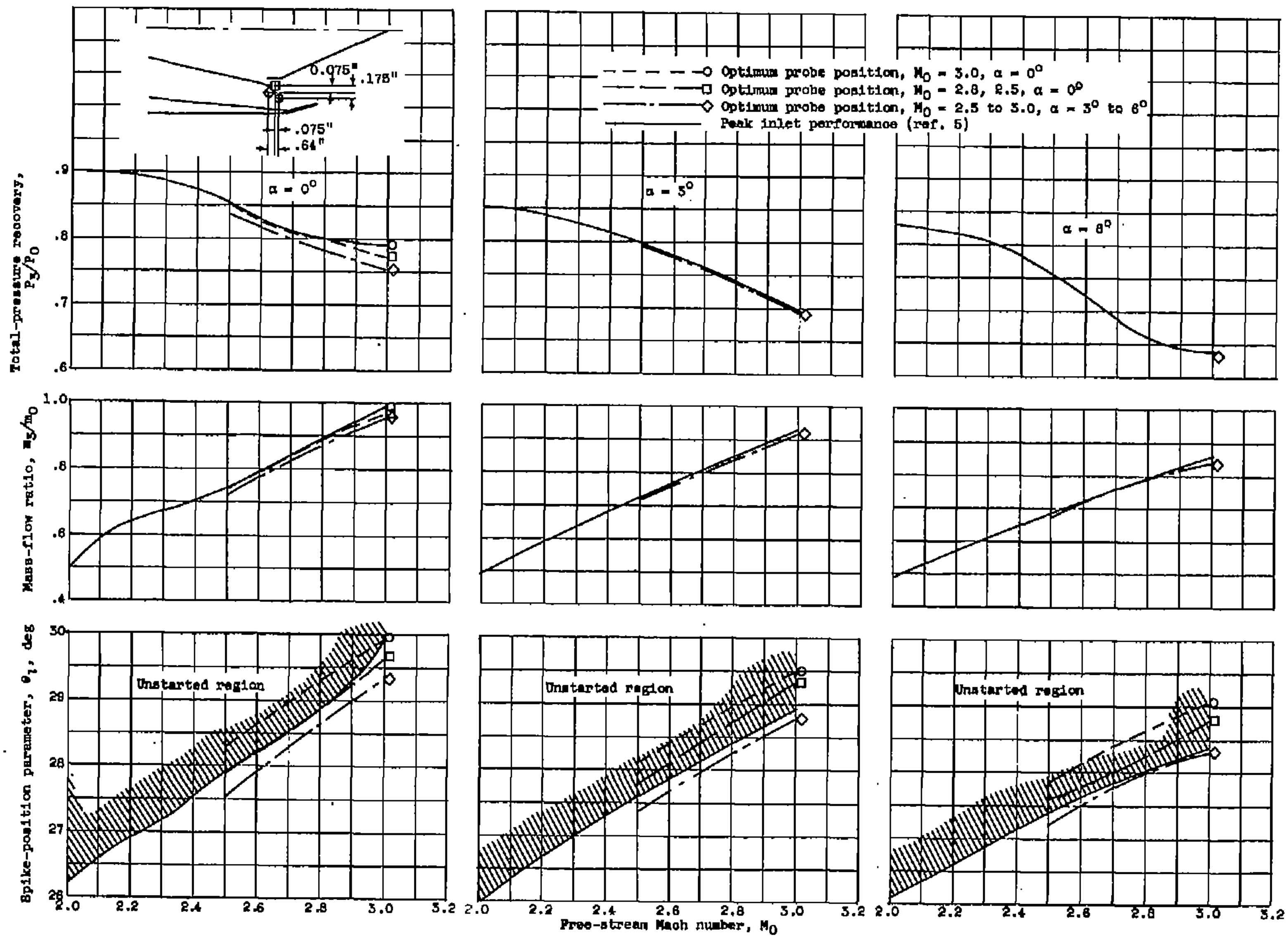


Figure 7. - Peak performance obtainable with optimum fixed probe position.

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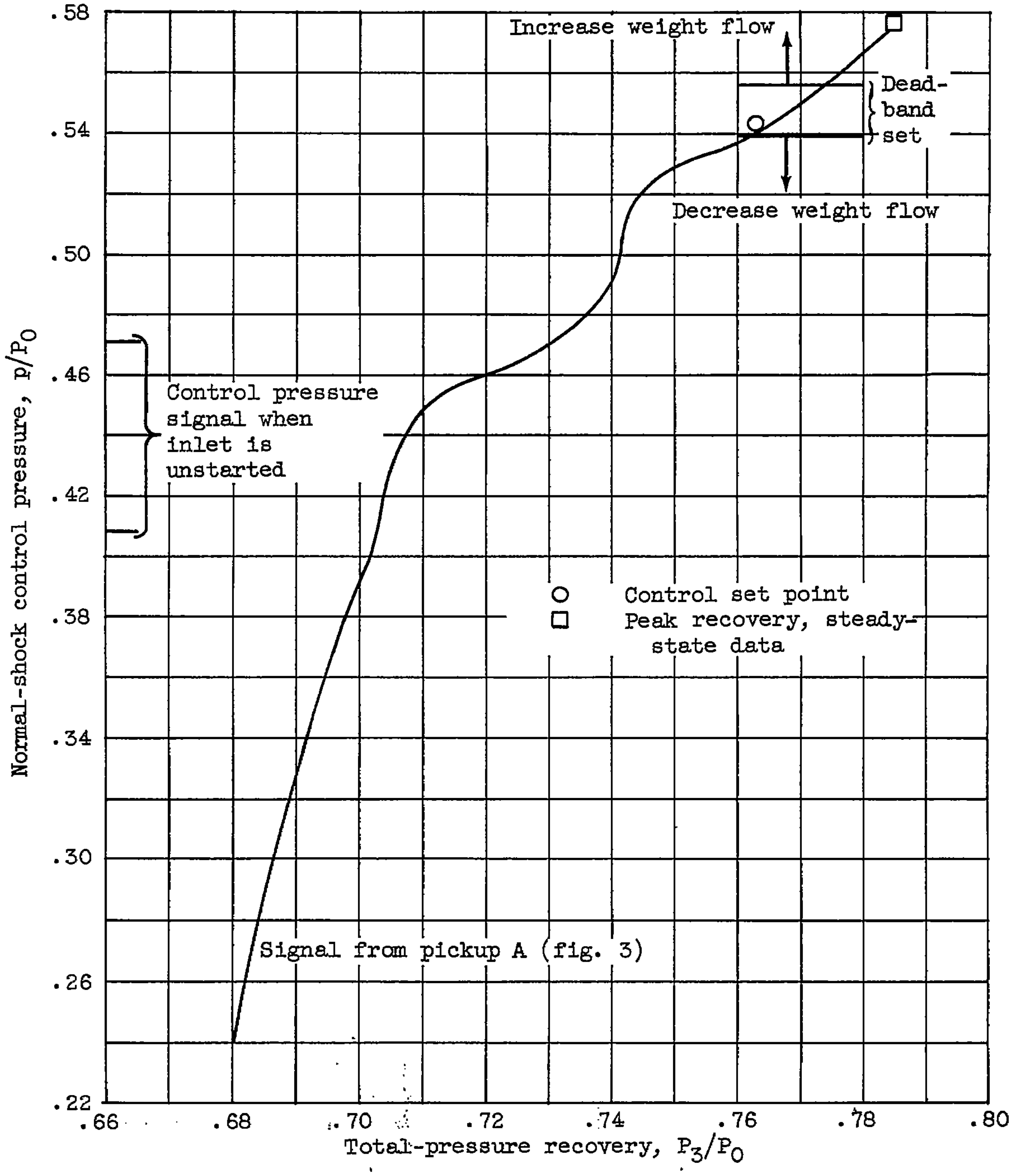
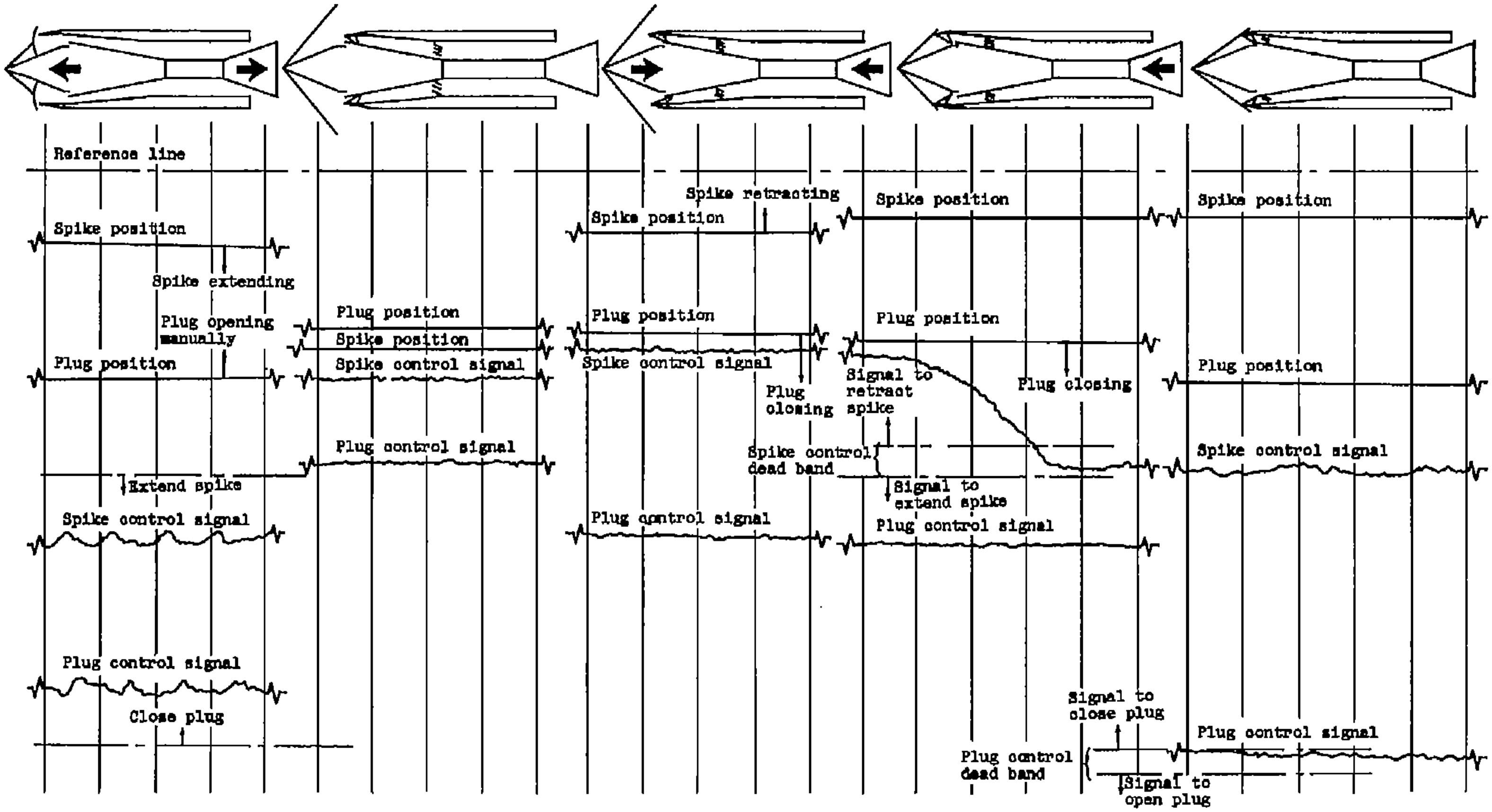



Figure 8. - Normal-shock control pressure signal. Free-stream Mach number, 3.0; angle of attack, 0°; spike-position parameter, 29.95°.




(a) Inlet unstarted. (b) Inlet started. (c) Control action. (d) Spike control set point. (e) Plug control set point.

Figure 9. - Trace of spike and plug control setting peak performance at Mach 3.0 and zero angle of attack.

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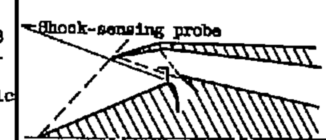
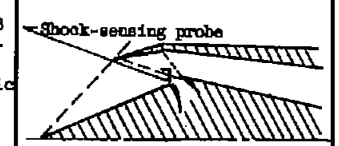
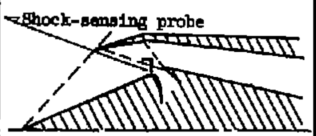
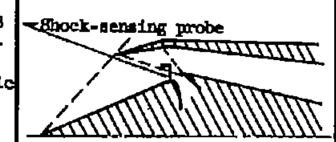
NOTES: (1) Reynolds number is based on the diameter of a circle with the same area as that of the capture area of the inlet.

(2) The symbol * denotes the occurrence of buzz.

## INLET BIBLIOGRAPHY SHEET

| Report and facility | Description | | | Test parameters | | | | Test data | | | | Performance | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Configuration | Number of oblique shocks | Type of boundary-layer control | Free-stream Mach number | Reynolds number $\times 10^{-6}$ | Angle of attack, deg | Angle of yaw, deg | Drag | Inlet-flow profile | Discharge-flow profile | Flow picture | Maximum total-pressure recovery | Mass-flow ratio | |
| CONFID. RM E58G08 Lewis 10- by 10-ft supersonic wind tunnel |   | 3 | Flush slot at center-body shoulder | 2.1 to 3.0 | 3.78 | $0^\circ$ to $6^\circ$ | $0^\circ$ | | | | | At $M_0$ = 3.0, $P_3/P_0$ = 0.785; $M_0$ = 2.0, $P_3/P_0$ = 0.875 | At $M_0$ = 3.0, $m_3/m_0$ = 0.98; at $M_0$ = 2.0, $m_3/m_0$ = 0.50 | The results indicate that the cowl-lip oblique shock provides a signal to position the spike and to start the inlet at Mach numbers 2.1 to 3.0 |
| CONFID. RM E58G08 Lewis 10- by 10-ft supersonic wind tunnel |   | 3 | Flush slot at center-body shoulder | 2.1 to 3.0 | 3.78 | $0^\circ$ to $6^\circ$ | $0^\circ$ | | | | | At $M_0$ = 3.0, $P_3/P_0$ = 0.785; $M_0$ = 2.0, $P_3/P_0$ = 0.875 | At $M_0$ = 3.0, $m_3/m_0$ = 0.98; at $M_0$ = 2.0, $m_3/m_0$ = 0.50 | The results indicate that the cowl-lip oblique shock provides a signal to position the spike and to start the inlet at Mach numbers 2.1 to 3.0 |
| CONFID. RM E58G08 Lewis 10- by 10-ft supersonic wind tunnel |   | 3 | Flush slot at center-body shoulder | 2.1 to 3.0 | 3.78 | $0^\circ$ to $6^\circ$ | $0^\circ$ | | | | | At $M_0$ = 3.0, $P_3/P_0$ = 0.785; $M_0$ = 2.0, $P_3/P_0$ = 0.875 | At $M_0$ = 3.0, $m_3/m_0$ = 0.98; at $M_0$ = 2.0, $m_3/m_0$ = 0.50 | The results indicate that the cowl-lip oblique shock provides a signal to position the spike and to start the inlet at Mach numbers 2.1 to 3.0 |
| CONFID. RM E58G08 Lewis 10- by 10-ft supersonic wind tunnel |   | 3 | Flush slot at center-body shoulder | 2.1 to 3.0 | 3.78 | $0^\circ$ to $6^\circ$ | $0^\circ$ | | | | | At $M_0$ = 3.0, $P_3/P_0$ = 0.785; $M_0$ = 2.0, $P_3/P_0$ = 0.875 | At $M_0$ = 3.0, $m_3/m_0$ = 0.98; at $M_0$ = 2.0, $m_3/m_0$ = 0.50 | The results indicate that the cowl-lip oblique shock provides a signal to position the spike and to start the inlet at Mach numbers 2.1 to 3.0 |

Bibliography

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